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Summary

A visual and acoustic survey for humpback whales in the Eastern Caribbean Islands from St. Kitts to Trinidad, and from Venezuela to Guadeloupe, was conducted from 9 February to 3 April 2000 on the 224 foot NOAA *RV Gordon Gunter*. The survey involved scientists from several Southeastern Caribbean nations and the United States, and was sponsored by IOCARIBE. This report presents the preliminary findings of this survey and was originally presented as working paper SC/52/AS/23 to the Scientific Committee of the International Whaling Commission. Three or four observers using 150 mm objective binoculars and handheld binoculars maintained a visual watch. The acoustic survey was conducted using directional (DIFAR) sonobuoys. Acoustic and visual whale detections of humpback whales were compared.

Visual and Acoustic Survey of Humpback Whales (*Megaptera novaeangliae*) in the Eastern and Southern Caribbean Sea: Preliminary Findings

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ABSTRACT

Knowledge of the abundance and distribution of humpback whales (*Megaptera novaeangliae*) in the eastern and southern Caribbean Sea is scarce compared to that documented in recent times for the principal breeding areas in the northeastern West Indies. A dual-mode survey for humpback whales was conducted in the eastern and southern Caribbean Sea to: (1) assess the current distribution and status of this species in areas where it was previously exploited to economic depletion; and (2) to evaluate the effectiveness of using both visual and passive acoustic survey methods to detect humpback whales in this region. The survey was conducted from the 75 m NOAA *RV Gordon Gunter*, and included most of the islands in the Lesser Antilles, Trinidad, Tobago, Barbados, and the north coast of Venezuela. The multi-national research team included scientists from Caribbean nations, Brazil, and the United States. Approximately 10,900 km of trackline was surveyed between 16 February and 29 March 2000 to correspond with the peak-breeding season of humpback whales in the West Indies. This included 4,331 km of "on-effort" visual survey conducted during Beaufort sea state ≤ 5 by teams of three observers using 25x "big-eye" binoculars and 7x handheld binoculars. The survey methodology followed standard NOAA/NMFS protocols for cetacean sighting surveys. A total of 33 visual sightings of humpbacks (n = 46, including three calves) was made during both the "on-effort" and "off-effort" visual survey modes combined. However, "on-effort" sightings without acoustic assistance were few (n = 9). Directional (DIFAR) sonobuoys, digital (DAT) tape recorders, and custom software were used to detect and record calling humpback whales in the survey area, to collect and archive samples of humpback song for analysis, and to direct the vessel to locations of humpback whales for biopsy and photographic identification sampling. Bearing angles from the sonobuoys to singing whales were calculated at sea to detect individual animals, and cross-bearings from more than one sonobuoy were used to determine their approximate locations. Humpback whale song was detected throughout the entire survey area, indicating that some humpback whales currently occupy areas where commercial whalers historically hunted them to depletion. A total of 74 acoustic detections of singing humpback whales were obtained from approximately 350 hr of monitoring of 176 sonobuoys deployed throughout the study area. These detections formed the basis of a preliminary estimate of the relative abundance of whales (not including calves) in the islands and coastal areas surveyed of 116 (95% CI: 72–293) whales in February, and 123 (95% CI: 77-313) in March. Biopsy samples and photographs were obtained from the ship and from two rigid-hulled inflatable boats. Sightings of other cetacean species are summarized. Ongoing post-survey analyses not reported here include: further development of acoustic based abundance estimation methods for humpback whales, geographical distribution of humpback whales detected acoustically, analysis of humpback whale song characteristics and structure throughout the West Indies, genetic relationship of humpbacks in the eastern and southern Caribbean Sea to other populations, and comparison of photographs with the North Atlantic humpback whale photographic identification catalogue. Although the observed low density of whales was partly attributable to the effect of strong trade winds and high sea states on visual survey conditions, the results of this survey suggest that the abundance of humpbacks in the eastern and southern Caribbean Sea is lower than it was during the 19th century. Furthermore, observed densities are one or two orders of magnitude lower than those recorded from the primary wintering areas in the northeastern Greater Antilles.

KEYWORDS: humpback whale, eastern and southern Caribbean, winter breeding ground, West Indies, visual survey, acoustic survey, abundance, distribution, acoustics, sonobuoy, biopsy, photographic identification.

INTRODUCTION

Most of the north Atlantic population of humpback whales (*Megaptera novaeangliae*) of approximately 10,600 animals (95% CI 9,300-12,100) is believed to overwinter in the West Indies region, where calving and mating occurs (Smith *et al.* 1999), although low numbers also are found in winter around the Cape Verde Islands in the eastern north Atlantic (Reiner *et al.* 1996). Research on humpback whales wintering in the western north Atlantic has been directed largely at those areas of the Greater Antilles and the northern portion of the Lesser Antilles with the greatest present day concentration of whales. These well studied areas include Silver Bank (Balcomb and Nichols 1982, Whitehead and Moore 1982, Mattila *et al.* 1989) and Navidad Bank off Hispaniola (Winn *et al.* 1975, Balcomb and Nichols 1982, Whitehead and Moore 1982), Mona Passage off Puerto Rico (Mattila and Clapham 1989), and the Virgin and Anguilla Banks (Mattila and Clapham 1989). In contrast, research on humpback whales in the remainder of the Lesser Antilles from Guadeloupe south to the coast of Venezuela has been relatively sparse (Winn *et al.* 1975, Levenson and Leapley 1978). These few studies and more recent local reports suggest the density of whales there is low. However, whaling data compiled by Townsend (1935), Mitchell and Reeves (1983), and Price (1985) indicate that the eastern and southern Caribbean Sea formerly supported a large-scale fishery for humpback whales (Fig. 1) (Reeves 1999). Nineteenth and early-twentieth century catches indicate that the eastern and southern Caribbean Sea hosted substantial numbers of humpback whales from January through May, while there is no evidence that humpbacks were taken in substantial numbers in the waters off Hispaniola and Puerto Rico (*i.e.*, Silver and Navidad Banks), which host large wintertime concentrations of whales today (Reeves 1999). Except for a small-scale traditional hunt conducted at Bequia since the 1920=s, commercial exploitation of humpbacks was abandoned by 1927 due to scarcity of whales.

North Atlantic humpbacks are listed as endangered under the U.S. Endangered Species Act (USFWS 1997), and are listed as vulnerable on the IUCN Red List of Threatened Animals (IUCN 1996). The apparent low abundance of humpback whales in the formerly important breeding habitat implies a possible failure to recover, for unknown reasons, despite the protection provided by these and other conservation measures. Determining the current status of humpbacks in the eastern and southern Caribbean Sea and understanding their recovery, or lack thereof, is essential for the management and conservation of this species (IWC 1998).

Thus, a multi-national research program was initiated in 1999 under the auspices of the International Oceanographic Commission' s IOCARIBE organization. The primary goal of the first year of the program was to develop a general picture of the regional abundance and relative distribution of humpback whales in the eastern and southern Caribbean relative to their recovery from commercial exploitation, and provide a foundation upon which to develop more quantitative population studies in the future. The specific objectives of this study were to:

1. Assess the feasibility of utilizing visual and passive acoustic survey methods to locate humpback whales in the southern and eastern Caribbean.

2. Survey areas where humpback whales were commercially hunted to depletion and determine whether whales continue to occur in these areas.

3. Determine the relative numbers of humpback whales that occur in the eastern and southern Caribbean Sea during the winter breeding season.

4. Obtain biopsy samples of skin and blubber for genetic analyses of the relationship between humpback whales in the eastern and southern Caribbean Sea and the rest of the north Atlantic, to determine the sex of individual animals, and to assess levels of contaminants carried in the whales blubber tissue.

5. Obtain photographic identification data to compare with the catalogue of north Atlantic humpback whales to further elucidate migratory behavior of humpbacks in this area and their summer destinations in the North Atlantic.

6. Obtain recordings of humpback whale song for comparison with song characteristics from other areas within the West Indies.

7. Opportunistically note the occurrence of other species of cetaceans and, if possible, collect biopsy and photographic identification information for stock and individual recognition.

Herein we report preliminary findings of research to address objectives 1, 2, 3 and 7. Analysis of data relevant to objectives 4, 5, and 6 are ongoing and additional findings will be reported in subsequent publications.

METHODS

To implement the research program, a first year multi-national survey was conducted on the 75 m long, U.S. NOAA *RV Gordon Gunter* from February 9 to April 3, 2000.

Study Area

The area of interest included the eastern and southern Caribbean Sea because, unlike more northern areas in the West Indies, little work on humpback whales has been conducted there. Specifically, the cruise track focused on the waters around the Leeward Islands (except for the Virgin Islands, the islands on Anguilla Bank, Sint Eustatius, Saba Island and Saba Bank), the Windward Islands, Barbados, Tobago, Trinidad, the islands in the southern Caribbean north of Venezuela, and the Caribbean coast of Venezuela (Fig. 2, Appendix 1). While transiting to and returning from the this study area, data were collected opportunistically from the waters north of Puerto Rico and the Dominican Republic in the eastern portion of the Greater Antilles.

Country Clearances

Clearance to conduct this multi-national survey in the waters of the nations of the eastern and southern Caribbean was requested and received from the governments of the Dominican Republic, St. Kitts and Nevis, Guadeloupe-Marie Galante, Martinique, St. Lucia, Barbados, Grenada, Trinidad-Tobago, and Venezuela. The nations of Dominica, Antigua-Barbuda, and St. Vincent and the Grenadines declined to provide vessel clearances. Upon arrival at the waters of those countries that had not provided clearance, all scientific operations were suspended and the vessel proceeded by right of innocent passage through that nation's waters. Scientific operations resumed once the vessel had entered the waters of a nation that had provided clearance. Lack of clearance from some nations prevented a complete synoptic survey of the region.

Survey Timing

Historical whaling records indicated that humpbacks formerly occurred throughout the Lesser Antilles, along the Caribbean coast of Venezuela, in the Gulf of Paria, and along the south coast of Trinidad from January through May (Reeves 1999). Recent research in the Greater Antilles and northern Leeward Islands suggest that the winter humpback whale population in these areas peaks from mid-February to mid-March (Mignucci-Giannoni 1998). For this reason, this survey of the eastern and southern Caribbean was scheduled during February and March to coincide with the peak of the winter breeding season.

Research Stages

There were three stages of operation during the survey - a shakedown-calibration stage, and two modes of data collection. Calibration and testing of the passive acoustic detection system occurred during transit from home port to San Juan, Puerto Rico, and consisted of testing the sonobuoy receiving system and adjusting the computer software to determine the bearings to singing humpback whales. In addition, visual observer teams utilized this time to conduct opportunistic observation shifts. The first data collection mode was "on effort" survey mode where simultaneous visual and acoustic surveys were conducted to detect humpback whales in the primary survey area for the purposes of evaluating distribution and relative abundance. When the weather allowed, visual and acoustic surveys were conducted simultaneously during daylight hours. The second mode of data collection was a monitoring mode where visual and acoustic searching was utilized to locate humpback whales for collection of biopsy samples, photographic identification sampling, and to record humpback whale songs (Fig. 2). Acoustic surveys sometimes continued after dark or began before sunrise in some areas to locate areas with humpback whales for the collection of biopsy and photographic identification data the following day. When singing humpback whales were detected after dark, the vessel remained in that area overnight and visual and acoustic surveys began at sunrise to locate the whales. While humpback whales were the species of interest, observations and sampling of other cetacean species encountered during the survey were conducted opportunistically.

Combined Visual and Acoustic Survey

It has been suggested that passive acoustic surveys offer advantages over visual surveys by allowing the detection of large cetaceans while submerged, by extending search distances, and by enabling surveys to be conducted during inclement weather and at night (Gordon and Steiner 1992, Leaper *et al.* 1992). Recent attempts to augment visual surveys with acoustic methods include surveys for blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*) (Clark and Fristrup 1997), bowhead whales (*Balaena mysticetus*) (Zeh *et al.*, 1993, Clark and Ellison 1989), sperm whales (*Physeter macrocephalus*) (Barlow and Taylor 1998), and humpback whales (Norris *et al.* 1999). While these efforts demonstrate that there are many difficulties with equating acoustic and visual detections, they do demonstrate advantages of acoustic surveys over some of the limitations of traditional visual surveys for cetaceans. In addition, the combination of visual and acoustic survey techniques provides data on whale abundance and behavior that would not be available from any one method alone (Clark and Fistrup 1997).

Male humpback whales sing a characteristic song, which is believed to function as a territorial display and/or to attract females (Payne and McVay 1971, Darling 1983, Darling *et al.* 1983, Glockner 1983, Tyack, P. 1981and 1983, Clapham 1996, Mobley *et al.* 1988,Winn and Winn 1978), or as a type of sonar to locate other whales (Frazer and Mercado 2000). The song of humpback males is long and complex, being composed of several themes sung in an invariant order, lasting from a few minutes to a half hour, with major frequency components centered below 2 KHz (Payne and McVay 1971) (Appendix II). Singers are usually alone, and may sing continuously for hours or even days (Payne and McVay 1971, Tyack 1981). Because male humpback whales are known to sing continuously during the winter breeding season, and because their song includes low frequency components, they lend themselves to passive acoustic detection methods. In view of the prevailing strong trade winds frequently encountered in the eastern and southern Caribbean, we wished to explore the potential use of passive acoustic methods to detect whales that otherwise might be missed by visual methods alone

Visual Survey: This survey was designed to provide a general picture of the abundance of humpback whales, and not to estimate absolute abundance. Thus, survey track lines were not exactly specified. Rather, survey track lines were developed to circumnavigate the coastlines of the islands surveyed (in areas where clearance had been granted), and to allow coverage of the coastal waters of northern Venezuela. Visual survey operations for cetaceans were conducted following standard NMFS survey protocols (Barlow 1995), modified to search for presence or absence of whales rather than for abundance estimation. On-effort switched to off-effort mode when either visual conditions deteriorated (due to sea state > Beaufort 5), or if the ship was in monitoring mode to locate whales for the collection of biopsy and photo-ID data, or to record humpback song. Visual observations were normally conducted from 0630 hrs to sunset (approximately 1930 hrs) each day.

Two teams of three experienced observers operated rotating 2-hr shifts during daylight hours, weather permitting (*i.e.*, no rain, Beaufort sea state ≤ 5, winds below approximately 22 kts.). Observers rotated through each of three observer positions every 30-min. to reduce fatigue. Observations were made from the flying bridge, located approximately 14 m above the sea surface. A port and a starboard observer each searched for cetaceans using 25X "big eye" binoculars within a 90^0 quadrant from the bow to the beam on each side of the ship. A third observer recorded data and maintained a search of the area near the ship using unaided eye and/or 7X hand-held binoculars. When cetaceans were sighted, the ship broke from its track and approached the cetaceans to confirm species and to estimate group size. Sighting data were recorded on a laptop computer using a data acquisition and logging software program that interfaced with the ship's global positioning system (GPS). Cetacean sighting data included species, group-size, presence of calves, bearing from the bow, linear distance from the ship when detected, and behavioral observations. Each night, observers filled out sighting forms, and these were checked for errors and reconciled with the day's computerized data log. Environmental data were recorded every half-hour with the rotation of observer positions, when conditions changed during a shift, and at the time of each sighing. Environmental data included sea state, surface temperature, water depth, weather, visibility, wind direction and speed, and sun glare in the observer's field of view. A continuous record of the ship's position, sea surface temperature (SST) and water depth was collected via the ship's onboard Scientific Sensor Collection System (SSCS).

Acoustic Survey: The survey platform, the NOAA *RV Gordon Gunter*, is well suited for both visual and acoustic surveys. She is a former U.S. Navy vessel designed to support passive acoustic operations. The ship is powered by diesel-electric engines that are acoustically quiet relative to power plants in other vessels, and produced minimal low-frequency background noise during survey operations. Monitoring to detect humpback whale song was conducted throughout the primary survey area and opportunistically in other areas with the use of directional sonobuoys (AN-SSQ-53D). These sonobuoys contain a compass in the sensor head and transmit three types of continuous signal back to the ship on a VHF radio carrier in an analog multiplexed format. These signals are acoustic sound pressure, east/west particle velocity and north/south particle velocity. These sonobuoys could be set to broadcast for up to 8-hrs.

The VHF radio signal from the sonobuoys was received by a pair of antennas mounted on the aft mast of the ship located at 85 feet above waterline. Sonobuoy frequencies were chosen near the frequency band of one or the other antenna, depending on the level of radio interference present on a specific frequency band. Radio reception ranges from the sonobuoys averaged 11-13 N.M. which, when the ship was running at survey speed (approximately 10 kts), allowed each sonobuoy to be monitored for approximately one hour and ten minutes before the ship moved out of radio reception range (Fig. 3). When in monitoring mode to locate whales for biopsy and photographic sampling, or to obtain recordings of whale song, sonobuoys were monitored continuously for up to 8-hrs and/or additional sonobuoys were deployed to allow extended periods of monitoring. The signals from the radios were recorded at a 48 kHz sampling rate on Sony TCD-D[1] digital audio tape recorders for further processing and for archival purposes, and were monitored in real time on laptop computers running SpectraPlus, a commercial signal-analysis software program.

The magnetic bearing to calling animals was determined by selecting a segment of the humpback song from the sonobuoy signal using the signal-analysis software program's spectrogram display computed on laptop computers using standard sound cards. This signal was then stored as a binary file, de-multiplexed, and the three de-multiplexed signals were processed by custom software written for this project. The de-multiplexing software produces a plot showing signal intensity as a function of frequency and bearing angle from 0^0 to 360^0 (Fig. 4). The bearing accuracy to a sound source using these buoys had a standard deviation of two degrees. Magnetic bearing

[1] The mention of trade names and commercial products does not imply an endorsement by the authors.

angles to calling animals from the sonobuoys were plotted as true bearings on navigational charts to determine the direction to the calling whale relative to the position of the ship. The vagaries of acoustic propagation in the ocean made it impossible to estimate range to a calling whale by received amplitude alone. However, when the same singing whale was detected on two or more sonobuoys with a sufficient baseline separation, it was possible to precisely locate the calling whale by crossing two or more bearings to determine the source.

RESULTS

The survey was conducted in two legs. The first survey Leg began in Pascagoula, Mississippi on February 9, 2000 and arrived in San Juan, Puerto Rico on February 15, 2000. This period included the shakedown portion of the survey where visual observation procedures and acoustic detection systems were tested and calibrated. Some opportunistic observations and recordings of humpback whale songs were obtained for song analysis while passing south of Silver and Navidad Banks off the north shore of the Dominican Republic. The vessel departed from San Juan on February 16, 2000 and entered the waters of the Lesser Antilles during the early morning hours of February 17, 2000. This portion of the survey covered the Leeward and Windward Islands including the waters around St. Kitts and Nevis, Guadeloupe, Martinique, St. Lucia, Grenada, Barbados, and Trinidad-Tobago, and concluded on March 7, 2000 in Trinidad. Areas not surveyed during this portion of the survey include Antigua and Barbuda, Dominica, and St. Vincent and the Grenadines because vessel clearance was not provided by these nations. The second Leg of the survey began in Trinidad on March 11, 2000 and included the Caribbean coast of Venezuela, some of the islands in the southern Caribbean north of Venezuela, Grenada, the east coast of Trinidad and Tobago, Barbados, Martinique, and Guadeloupe. The vessel departed the Lesser Antilles on March 27, 2000. Opportunistic visual and acoustic surveys continued through March 29, 2000 while in transit to Puerto Rico and while passing south of Silver and Navidad Banks to attempt to obtain additional sightings, photo-identifications, and biopsy samples, and to obtain recordings of humpback whale song from this area for comparison with recordings made approximately one month earlier. The survey terminated on April 3, 2000 in Pascagoula.

Our original intent was to conduct visual and acoustic surveys simultaneously for side-by-side comparison. Unfortunately, the prevailing weather conditions severely limited the visual survey efforts, and low numbers of sightings precluded statistical comparison of the two survey methods.

Visual Survey

During the 37 days at sea, a total of 10,900 km was surveyed. Of this, 4,331 km or 40 % was visually surveyed on effort during daylight hours and sea state conditions $\leq$ Beaufort No. 5 (Table 1). Daily visual effort ranged up to 13.5 hours/day and 242 km/day and averaged 7.5 hours/day and 124 km/day.

A total of 196 cetacean groups of at least 19 cetacean species were sighted (Table 2). These included a total of 33 sightings comprising 46 individual humpback whales (Table 3): 22 sightings were of single whales, 9 were sightings of two whales, and 2 were sightings of 3 whales that included a mother-calf pair and a third whale. Sightings during periods of simultaneous visual and acoustic surveys included 21 sightings comprising 26 whales (Fig. 5). The observers without acoustic detection saw nine of these sightings (three mother-calf pairs and 6 other groups). The remainder was first detected by the acoustic survey and the vessel was directed to that area before the visual observers detected them. Seventy-two percent of all the humpback sightings were in water 100 m deep or shallower, while 28% were in deeper waters including 4 sightings in water in excess of 3,000 meters. All three mother-calf pairs were sighted in water 33 m or less in depth.

Acoustic Survey

Data Collection: During survey mode an attempt was made to place sonobuoys such that the VHF radio signal detection fields overlapped to allow continuous coverage while underway. Additional sonobuoys were placed at various locations to locate singers and to direct the vessel to those locations to attempt biopsy and photographic identification sampling. On at least five occasions multiple sonobuoys were placed in one location to allow monitoring and recording of humpback whale songs for up to 8-hr or longer, and this information was used to develop a correction factor to estimate the number of non-singing whales (see below). The locations of all 176 sonobuoys deployed during the survey are shown in Figure 6.

Humpback whale song was detected in each portion of the eastern and southern Caribbean surveyed. A total of 74 acoustic detections of singing humpback whales were obtained within the primary survey areas (Table 4). The placement of sonobuoys around the islands and coastlines, and the "true" bearings to humpback whale singers were determined in real time during the survey and are shown in the Figures in Appendix III. The "true" bearing angles to singing whales detected from each sonobuoy location (circle) are shown in the figures as vector-bars (lines). The length of the vector-bars representing bearing angles is arbitrary and not indicative of the amplitude of the received signal strength of the song or distance to the singing whale. The total number of singing whales detected on a single sonobuoy is noted in parentheses. Occasionally more than one singer was detected on the same or similar bearings as evidenced by a difference in the received amplitude of the acoustic signals and/or differences in the starting and stopping patterns of songs by the different singers. In such cases, more than one whale is noted for a single bearing on the Figures. For clarity of presentation, a maximum of two bearing angles, representing at least two singing whales, is plotted for each sonobuoy. Ongoing post-survey analysis of the data tapes may refine these estimates of the number of detections of singing humpback whales.

In some instances, multiple bearings from multiple buoys intersected, indicating the location of a calling humpback. The presence of whales was confirmed by directing the vessel to these locations. If whales were found at these locations, and the sea state allowed, the small rigid-hull inflatable boats were launched to attempt to collect biopsy and photographic identification samples (see below).

Estimation of Minimum Abundance Based on Acoustic Detections

One goal of acoustic surveys is to develop a reliable methodology for estimating abundance of cetaceans. To date such studies have illustrated some advantages of acoustic surveys over traditional visual surveys (*e.g.*, extended detection range, nighttime surveys), but have also pointed out methodological difficulties that will need to be overcome for acoustic surveys to provide reliable and precise abundance estimates for cetaceans. These include estimation of detection range, and estimation of whales present but not detected acoustically.

Detection Range Estimation: The calculation of effective strip width is fundamental to the estimation of abundance from strip transect surveys (Buckland *et al.* 1993). The acoustic detection range for a sonobuoy is analogous to the perpendicular distance from the trackline of a visual observation of an animal during a line transect. Observed distributions of perpendicular detection distances are used to estimate the effective strip width, or detection function f (0) - the probability of detecting an animal at various distances from the transect line. Empirical measurements of detection range for sonobuoys could be used in a similar manner to estimate acoustic effective strip width by fitting a probability density function to the observed distribution of detection distances obtained during this survey. As with visual data, effective strip width would be affected by a number of factors affecting the observer's detection ability (e.g., sea state, through air visibility, etc.). An acoustic detection function would similarly be affected by the transmission characteristics of sound through water including depth, bottom topography, temperature, salinity, depth of thermocline, etc. To explore this potential, we gathered preliminary data on the realized detection range of the sonobuoys utilized in this survey.

The detection ranges of humpback whale songs were estimated in real time during the survey from the distance between a sonobuoy and the intersection of bearings from that sonobuoy and others receiving the same humpback song. In practice, acoustic detections appeared variable from less than 10 N.M. in shallow water with a high Beaufort sea state, to as much as 36 N.M. or more in deep water areas with a strong thermocline and relatively low Beaufort sea state. These impressions were formed from a number of specific cases where detected singers were pursued for visual verification of location, and from a series of cases where singers located from the intersections of acoustic bearings (cross-bearings) continued to be detected on subsequent sonobuoys located at known distances from those locations. Shorter-range locations and relative signal strengths were estimated from the cross-bearings from multiple sonobuoys with sufficient baseline separation. The cross-bearing baseline length was limited by radio range making localization imprecise with increasing ranges (baseline limit was approximately 12 N.M.). Sea states were typically high throughout the entire study area, as high as Beaufort 6 and averaging 3.7, and also limited detection range.

Cases of only 5 to 10 N.M. detection ranges were common in some near-shore areas, like off east Trinidad, where the bottom topography is complex with water depths highly variable from a few meters to 50 meters or more. It was common to be unable to detect the same whales on two buoys separated by as little as 5 N.M., presumably due to the shadowing effect of shallow banks and reefs. Similarly, a more distant sonobuoy received a louder song than the closer buoy. In such instances, difference in the time of arrival of the song signal at different sonobuoys was also used to determine relative distances of the singer from multiple sonobuoys. This method was used most often to check cross-bearings and to determine if the animal was moving. In other instances where whales were detected over deep water, longer detection ranges were noted. One instance of a 36 N.M. detection range occurred off the leeward side of Martinique with a sea state of Beaufort 2. This singing whale was tracked with the ship, and was recorded on five sonobuoys at various intermediate ranges before the animal was localized and observed visually. Ongoing post survey analyses of the sonobuoy tapes will re-calculate detection ranges for sonobuoys that received signals from the same singers, and from this information an acoustic detection function will be developed for various water depths encountered.

<u>Estimation of Whales Not Detected Acoustically:</u> The extrapolation of acoustic detections to estimate abundance of whales has been attempted by a number of researchers (Winn *et al.* 1975, Barlow and Taylor 1998, Clark and Ellison 1988 and 1989, Norris *et al.* 1999), and remains a challenging and rapidly evolving area of marine wildlife management science. During this survey, when the ship was directed to the location of an acoustically detected whale, more than one humpback was often sighted suggesting that not all whales in the area were singers. In addition, three female-calf pairs were detected by the visual observers, but not by the acoustic survey. Clearly, the number of acoustically detected animals was an underestimate of the number of whales present in the survey area. With this recognition, we attempted to estimate the total number of male and female humpback whales in those areas surveyed.

The minimum numbers of humpbacks acoustically detected around each of the island areas surveyed are shown in Table 4. Singing humpback whales whose sex has been determined visually or genetically have exclusively been males. Thus, whales detected acoustically were assumed to be males and the number of acoustic detections was assumed to be the minimum number of whales in the survey area. To estimate the total number of whales in each island area (N_t), the total number males ($N_{M.}$) was first estimated from the number of singers ($N_{singers}$) by examining the rate at which singers were detected during periods of continuous monitoring. The number of females (N_f) was estimated from the ratio of females-to-males observed on the better-studied winter grounds of Silver and Navidad Banks off the north coast of the Dominican Republic. The total number of humpback whales (N_{Total}) within the individual island areas surveyed (excluding calves) was estimated as the sum of N_t for each island area where:

$$N_{Total} = \sum_{i=1}^{n} N_t = \sum_{i=1}^{n} N_m + N_f \qquad (1)$$

where n = the number of areas surveyed.

Estimation of Males: The cumulative number of singers detected from a sonobuoy will increase with time as whales commence to sing until, after some period, all of the whales are detected. By fitting a discovery rate curve to the cumulative increase in singers and extrapolating the resulting curve (cumulative number of singers versus time) to an asymptote, the total number of singers can be estimated. The fraction of this total that would be detected after X-number of hours is determined from the fit of the discovery curve. This information was used to develop a correction factor to account for the singing whales missed due to survey monitoring intervals being too short to coincide with a period of song production.

The hourly accumulation of unique acoustic detections (individual singers) were determined from tape records from 5 sonobuoys (or groups of closely spaced sonobuoys) that were monitored for 8-hrs or more during the cruise (Fig 7). These sonobuoys were deployed at various locations throughout the survey area, including Venezuela (March 14, Sonobuoy #136; March 16, Sonobuoys #143-146), Trinidad (March 21, Sonobuoys #167 and 168), Barbados (March 22, Sonobuoy #172 and 173), and Guadeloupe (March 25, Sonobuoy #191), and therefore were considered representative of singing behavior throughout the survey area. The initial detection of 5 whales was, thus, the sum of the initial detection on all 5 sonobuoys. Whales identified as new singers (*i.e.* having a distinctly different bearing angles) were summed over time to create a cumulative total during the 8-hr continuous monitoring period. Whales that stopped singing during the monitoring period were not subtracted from the cumulative total to indicate the total number of acoustic detections possible within the active life of a sonobuoy, and not the number of whales present at the end of an 8-hr monitoring period. Dividing the number of whales detected at the end of the 8-hr period (n = 11) by the number detected within the first hour of monitoring (n = 6), gives a detection probability for singers, or adult male humpback whales, of 55%. The total number of adult males ($N_{M.}$) is then estimated as:

$$N_{M.} = N_{singers} \, / \, 0.55. \qquad (2)$$

A crude binomial standard error for this detection probability is estimated from the sample size as,

$$S.E.(p) = \sqrt{(pq / N)} \;\; = 0.15 \qquad (3)$$

Where p = 0.55, q = (1 B p) = 0.45, and N = 11. The 95% confidence interval for this detection probability is calculated as 0.55 $\pm$ 0.334 or, 0.216 to 0.884.

There are two biases associated with this estimated detection probability. Because the plot of the cumulative number of detections with time does not show a clear asymptote at 8-hrs (Fig. 7), it is possible that some males present at the start of a monitoring period had not yet started to sing. Not accounting for these non-singing males biases the estimated detection probability of singers (*i.e.*, males) upwards. However, on three separate occasions, twice in Venezuela and once in Trinidad, multiple buoys covering the same area, but deployed at different times, were combined to represent one monitoring period, spanning time greater than 8-hrs. In each of these occasions, no new humpback whales were heard singing after 8 hrs, suggesting the estimated detection probability of 55% is valid. Alternatively, new animals may have entered the area being monitored and started to sing within the 8-hr window, or a singer could have ceased singing and moved to a new location and commenced to sing and been miss-identified as a new singer. This would lead to a negative bias in the detection probability for males.

Estimation of Females: The proportion of female to male humpback whales on the breeding ground of Silver and Navidad Banks in the Greater Antilles was 35:65 (Smith *et al.* 1999). Using this proportion, the number of females in the survey area was estimated as:

$$N_f = N_{M.} (35/65). \qquad (4)$$

Estimation of Calves and Immature Whales: The proportion of calves in the population during the winter breeding season is very difficult to estimate because it will likely vary with the proportion of adult females, individual female fecundity, area, and time of the season as progressively more calves are born. Unfortunately there is no single parameter value that can be used, and for this reason the number of calves was not estimated here. Estimation of immature whales is also problematic and was not attempted here.

Estimation of Total Whales: The total estimated number of humpback whales in the portions of the eastern and southern Caribbean surveyed, excluding calves, is the sum of the estimated number of animals from each island area. Equation (1) then becomes:

$$N_{Total} = \sum_{i=1}^{n} (N_{singers} / 0.55) + ((N_{singers} / 0.55)(35/65)) \qquad (5)$$

where n = the number of areas surveyed (Table 3).

The number of acoustic detections obtained from the areas surveyed during February including the islands and the Caribbean coast of Venezuela surveyed in early March was 41 (Table 4). The estimated number of singers was 75, and the estimated number females was 40, for an estimated total number of humpback whales, except for calves, of 116 (95% CI = 72 B 293). The number of singers detected in the areas surveyed in March was 44, which gave an estimated 80 males, and 43 females for a total estimate of 123 (95% CI = 77 B 313) whales.

Acoustic Assistance with Biopsy and Photo-Identification Sampling

Throughout the survey, efforts were directed towards obtaining biopsy samples and photographs of humpbacks in the east Trinidad area to identify individuals and to assess their relationship with the greater North Atlantic humpback whale population.

The intersections of multiple bearings from multiple buoys were utilized to determine the location a singing humpback whale. The presence of whales at these locations was confirmed by directing the vessel to the point where bearings crossed while maintaining a visual watch of the area. If whales were found at these locations, and the sea state allowed, the small rigid-hull inflatable boats were launched to attempt to collect biopsy and photographic identification samples (see below). Observers on the large vessel maintained a watch for surfacing whales and directed the small boats to them via VHF marine band radios. During these operations, more than one whale was frequently sighted at or near the location of a singer that was detected acoustically.

Observers noted that the whales spent little time at the surface relative to their dive times. Whales surfaced to blow 1-5 times and then submerged for 20 min. or longer, making it difficult for the small boat to approach close enough to obtain biopsy or photographic samples. We experienced some success in predicting the time of surfacing of a whale based on an audible decrease in song amplitude just before the whale's first surfacing, which may be the result of surface cancellation effect as the sound source moves nearer the surface. However, in practice this proved unreliable as a predictor of a whale surfacing because some whales continued to sing throughout their surfacing periods. This made it difficult to predict surfacing intervals, and to alert the small boats to initiation of a surfacing sequence.

Nineteen biopsy samples were obtained from cetaceans during the cruise, including 3 humpback whales. Nine humpbacks were photographed for individual identification. We cannot say with assurance that a whale that was biopsy sampled was a singer.

Song Analysis

Humpback whales are believed to gradually modify the composition and organization of their songs during the course of a winter season, with changes occurring more rapidly in some years than in others. At the beginning of the following season, the song structure is basically the same as it was at the end of the previous breeding season (Payne, *et al.* 1983, Payne and Payne 1985). Although what appear to be many variations of humpback songs were recorded during this survey, one song was heard most often throughout the second leg of the cruise (Appendix II). Recordings of this song were obtained in the vicinity of Barbados, Martinique, Guadeloupe, and along the north coast of Venezuelan and eastern coast of Trinidad.

Additional recordings of humpback song were obtained from St. Croix to the Bahamas to investigate the continuity of the song throughout the study area. Songs recorded just south of Puerto Rico and north to Silver and Navidad Banks appear to be similar to the song recorded from sonobuoys deployed further south within the Windward Islands. Obvious differences among songs recorded in different locations within the eastern and southern Caribbean include the number of times a syllable is repeated, the complexity of a particular syllable, and slight changes in the start and end frequency of a given element. Sections of the most frequently encountered song were evident in songs from other survey areas, such as off the coast of Grenada, with one or more phrases or motifs replaced by a novel element. This difference was noticeably common in the vicinity of Silver and Navidad Banks, where high frequency chirps replaced much of the mid-frequency part of the songs recorded in areas further to the south.

The analysis of humpback song recorded during this survey is ongoing and findings will be reported in subsequent publications.

DISCUSSION

The estimate of abundance from this study is a very approximate figure, but it appears to corroborate the findings of the studies by Winn *et al.* (1975) and Levenson and Leaply (1978) that relatively few humpback whales utilize this region compared to the current primary wintering areas in the northeastern Greater Antilles. Winn *et al.* (1975) surveyed what they presumed was the entire range of humpback whales in the West Indies based on Townsend's (1935) analysis of catch distributions of nineteenth-century whalers. They generally covered the main areas visited by this survey but did so a month earlier (January 25 to February 24) in 1972. They detected relatively small numbers of whales in the eastern and southern Caribbean (visual detections = 12, acoustic detections = 22), but observed many more whales in the northern Leeward and Greater Antilles portions of the humpbacks' winter range, which is consistent with the findings of more recent surveys in those areas. They proposed that low number of humpbacks in the eastern and southern Caribbean could be the result of: (1) the timing of their survey being too early to coincide with the main seasonal influx of whales, and/or (2) the ongoing hunt at Bequia of 0-6 animals per year at that time which may have kept the population suppressed due to the fact that this hunt targeted female-calf pairs. Other possibilities are that: (3) the catch positions from American whaleships were under-representative of the nineteenth-century distribution and relative abundance of humpbacks in different parts of the West Indies; (4)

the winter distribution of humpbacks in the West Indies has changed since they were hunted in the nineteenth century (Reeves 1999); or (5) that the winter distribution of humpback whales in the eastern and southern Caribbean is analogous to that found in the better studied northern Leeward Islands (*i.e.*, Anguilla and Virgin Banks), where winter abundance is generally low, but photo-identification of individuals indicates that many of the whales that transit the area are from known feeding grounds, and that others have been observed on the major winter congregating areas of the Greater Antilles (*i.e.*, Silver and Navidad Banks) (Mattila and Clapham 1989).

The apparent low abundance of humpback whales in the formerly important breeding habitat implies a possible failure to recover. Humpbacks in the eastern and southern Caribbean Sea might be the descendants of a distinct population that was greatly reduced by whaling and that has failed to recover from historical exploitation. However, Stevick *et al.* (1999) reported photographic matches of two humpback whales between the Lesser Antilles and north Atlantic feeding grounds: one animal was photographed on Saba Bank and then in Newfoundland, and the second match was between Grenada and Greenland. Another individual was re-sighted in Puerto Rico and Dominica, demonstrating an exchange between the eastern Caribbean and the more northerly breeding area in the Greater Antilles. Although a small sample, these matches support the hypothesis that humpbacks wintering in the West Indies belong to a single population that distributes itself throughout the region during the winter.

The results of this survey confirm that humpback whales continue to use the waters of the eastern and southern Caribbean in winter, though in lower numbers than are apparent in the historical data. The Gulf of Paria was apparently a major gathering ground for humpbacks (Reeves 1999), although we found no evidence of its use by humpbacks today. The abandonment of this area could be attributable to disturbance from extensive oil and gas development and production that occurs off the southeastern end of Trinidad and in the southern Gulf of Paria, along with shipping traffic into and out of the Port of Spain harbor. Our observations of female-calf pairs confirm that the Lesser Antilles and the Caribbean coast of Venezuela serve as serve nursing, mating and possibly calving grounds today, which is consistent with historical observations by whalers and observations by Winn and Winn (1978).

Humpback whale song was heard throughout the entire survey area. However, except for three sightings north of Puerto Rico, visual sightings of humpback whales were made only in the areas from Guadeloupe south to Trinidad-Tobago and Venezuela (Fig. 5). Sixteen humpback sightings occurred in waters east of Trinidad and Tobago (including one female-calf pair), 8 in Guadeloupe and Marie Galante waters, and 2 sightings each off Barbados and Martinique. Another female-calf pair was sighted off Venezuela, and the remaining sighting of a female-calf pair and a third animal was sighted off the southern end of Grenada (Table 2). The paucity of visual sightings compared to the number singing whales detected acoustically throughout the eastern and southern Caribbean can be partly attributed to the generally high Beaufort Sea State (5+ on average) and the relatively brief periods that humpback whales spent at the surface. This result clearly demonstrates the advantage of acoustic survey methods over visual methods in areas with prevailing winds and poor visibility.

The number of visual and acoustic detections presented here is not representative of the total population of humpback whales around each island or survey region, nor is it representative of the wintertime population in the eastern and southern Caribbean. Lack of clearance from some Caribbean nations precluded a synoptic assessment of the presence of humpback whales in the entire eastern and southern Caribbean region. At best, the number of detections presented here represent a minimum number of humpback whales that currently reside in the eastern and southern Caribbean during the winter, and perhaps best indicate that this region remains a part of this specie's winter range. Nonetheless, it is difficult to reconcile the densities observed here with those that are implicit in the historical catch data. Either this is a separate population that has not recovered from commercial whaling (which seems unlikely), or there has been a major shift in the location of the primary breeding aggregation since the 19th century. Clapham and Hatch (2000) suggest that this shift reflects a characteristic of the humpback's mating system, whereby only one major aggregating point occurs in any oceanic breeding range; they argue that this point shifted (largely stochastically) from the southeastern Lesser Antilles to the eastern portion of the Greater Antilles following overexploitation in the 1800's and early 1900's in the former area.

Whichever is the case, we are hopeful that future requests for clearance to conduct surveys for humpback whales will be granted to allow more complete coverage of this portion of the species' winter range to assess its status in the region. Such status assessments are important, particularly in the Grenadines where humpback whales used to be relatively abundant until 19th and 20th century commercial whaling over exploited the population, and where there continues to be a subsistence hunt.

Ongoing genetic analyses of the biopsy samples and analysis of identification photographs obtained during this survey along with the analysis of song similarities and differences throughout the region, will contribute toward understanding the relationship between humpback whales wintering in the eastern and southern Caribbean and those that frequent summer feeding grounds in the north Atlantic and the winter breeding grounds in the Greater Antilles. In addition, these analyses may help to test the hypothesis that humpbacks from the West Indies mix with whales from the Cape Verde Islands, as suggested by similarities in their songs (Reiner *et al.* 1996). These analyses may also assist in testing the hypothesis that humpbacks from the south Atlantic visit the southern Caribbean during the boreal winter and mix with north Atlantic whales, as has been noted for Pacific humpbacks (Acevedo and Smultea 1995).

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Table 1. Survey schedule, locations visited, and visual survey effort

DATE	LOCATON	EFFORT HOURS	TRANSECT KILOMETERS	AVERAGE SEA STATE
LEG 1:				
09-Feb-00	Depart Pascagoula	-	-	-
15-Feb-00	Arrive San Juan., Puerto Rico	-	-	-
16-Feb-00	Depart San Juan, Puerto Rico	-		-
17-Feb-00	St. Kitts and Nevis	4.5	78.3	4.9
18-Feb-00	St. Kitts and Nevis	8.7	154.9	5.3
19-Feb-00	Guadeloupe	6.9	126.5	5.3
20-Feb-00	Martinique	6.9	119.4	3.8
21-Feb-00	Martinique	6.6	114.8	3.4
22-Feb-00	St. Lucia	4.1	66.0	4.3
23-Feb-00	Grenada	8.4	133.1	4.3
24-Feb-00	Barbados	5.2	89.3	4.1
26-Feb-00	Barbados	6.4	124.0	3.0
27-Feb-00	Trinidad and Tobago	8.5	148.6	3.3
28-Feb-00	Trinidad and Tobago	4.2	58.1	3.8
29-Feb-00	Trinidad and Tobago	10.7	211.1	4.0
01-Mar-00	East Trinidad	8.0	127.3	5.0
02-Mar-00	East Trinidad	4.8	82.1	3.7
03-Mar-00	Trinidad and Tobago	2.5	38.0	5.0
04-Mar-00	East Trinidad	14.6	227.5	4.3
05-Mar-00	East Trinidad	6.6	111.6	4.2
06-Mar-00	East Trinidad	0.3	4.3	5.0
07-Mar-00	Arrive Port of Spain, Trinidad	-	-	4.3
TOTALS:		117.9	2014.9	4.3
LEG 2:				
09-Mar-00	Deapart Port of Spain	-	-	-
11-Mar-00	Venezuela	-	-	-
12-Mar-00	Venezuela	4.9	90.0	5.0
13-Mar-00	Venezuela	10.3	142.7	5.0
14-Mar-00	Venezuela	4.9	83.1	4.2
15-Mar-00	Venezuela	9.2	151.4	3.2
16-Mar-00	Venezuela	8.2	131.3	4.0
17-Mar-00	Venezuela	9.2	76.6	4.2
18-Mar-00	Venezuela	-	-	-
19-Mar-00	Grenada	9.0	83.1	2.7
20-Mar-00	Trinidad and Tobago	11.0	142.2	3.5
21-Mar-00	Trinidad and Tobago	10.6	157.9	3.4
22-Mar-00	Barbados	7.3	107.6	2.9
23-Mar-00	Arrive/Depart Bridgetown, Barbados	9.9	109.9	2.4
24-Mar-00	Martinique	3.4	55.2	2.1
25-Mar-00	Guadeloupe	9.5	181.1	2.6
26-Mar-00	St. Kitts and Nevis	6.3	116.7	2.6
27-Mar-00	Arrive San Juan, Puerto Rico	7.1	135.9	1.3
28-Mar-00	Depart San Juan, Puerto Rico	-	-	-
29-Mar-00	Dominican Republic	-	-	-
30-Mar-00	Cuba	-	-	-
31-Mar-00	Transit	6.2	128.01	3.2
01-Apr-00	Transit	11.5	237.3	2.9
02-Apr-00	Transit	11.8	242.2	3.7
03-Apr-00	Arrive Pascagoula	10.6	197.1	3.7
TOTALS:		160.9	2569.3	3.3

Table 2. Sightings of cetacean species

	Cetacean Group Sightings				Water Depth (meters)			Sea Surfac
Species	n	Mean	(SE)	Range	Mean	(SE)	Range	Mean
Balaenoptera physalus	1	1.0			119	(63.0)		23.3
Balaenoptera edeni	5	1.6	(0.24)	1 - 2	63	(19.7)	23 - 117	24.1
Megaptera novaeangliae	33	1.4	(0.11)	1 - 3	586	(224.4)	27 - 5029	16.8
Physeter macrocephalus	16	2.7	(0.62)	1 - 11	1784	(169.4)	877 - 2498	27.2
Kogia simus	2	3.0			1648	(850.0)	799 - 2498	26.7
Ziphius cavirostris	1	3.0			1499			27.2
Mesoplodon densirostris	1	2.0			3658			27.8
Peponocephala electra	1	38.0			1699			26.7
Pseudorca crassidens	1	4.0			309			27.0
Steno bredanensis	6	9.4	(0.68)	8 -11	54	(8.2)	31 -74	27.2
Lagenodelphis hosei	1	70.0			1280			26.5
Delphinus spp.	11	18.1	(5.46)	3 - 60	56	(4.2)	24 - 71	23.9
Tursiops truncatus	19	13.5	(2.99)	1 - 50	399	(139.0)	20 - 2498	26.6
Grampus griseus	1	3.0			2498			27.4
Stenella spp.	5	29.2	(16.29)	3 - 90	1129	(725.0)	249 - 4006	26.4
Stenella attenuata	10	37.1	(15.90)	5 - 175	1126	(93.0)	49 - 2506	26.6
Stenella frontalis	8	16.0	(4.63)	4 - 40	163	(104.2)	48 - 893	26.3
Stenella longirostris	2	105.0	(70.00)	35 - 175	1556	(457.2)	1097 - 2012	26.6
Balaenoptera spp.	4	1.2	(0.25)	1 - 2	77	(24.3)	9 - 119	24.0
Kogia spp.	2	3.7	(0.88)	2 - 5	2225	(363.0)	1499 - 2597	27.5
Mesoplodon spp.	2	2.0	(1.00)	1 - 3	2478	(180.0)	1299 - 3658	27.6
Globicephala spp.	7	7.0	(2.28)	3 - 18	1746	(252.0)	1006 - 2835	26.7
T. truncatus/S. frontalis	7	8.1	(1.47)	3 - 12	49	(2.1)	42 - 55	26.7
P. electra/F. attenuata	1	16.0			1536			26.8
Unidentified dolphin	26	9.6	(1.93)	1 - 30	902	(212.0)	38 - 4024	26.1
Unidentified small whale	1	1.0			26			26.3
Unidentified large whale	12	1.3	(0.14)	1 - 2	601	(348.3)	35 - 4024	23.4
Unidentified odontocete	9	1.6	(0.29)	1 - 3	1859	(472.2)	165 - 4024	26.8

Table 3. Sightings of humpback whales (* = female-calf pairs)

DATE	SPECIES	GROUP SIZE	POSITION	SST (C)	DEPTH (m)	SIGHTING EFFORT
21-Feb-00	*Megaptera novaeangliae*	1	14 13' 61 30'	26.7	2745	off
23-Feb-00	*Megaptera novaeangliae**	3	11 57' 61 50'	26.9	33	on
27-Feb-00	*Megaptera novaeangliae*	1	11 07' 60 31'	27.2	77	off
28-Feb-00	*Megaptera novaeangliae**	2	10 30' 60 36'	27.2	33	on
28-Feb-00	*Megaptera novaeangliae*	1	10 25' 60 47'	27.3	31	on
01-Mar-00	*Megaptera novaeangliae*	1	10 50' 60 55'	27.1	53	off
02-Mar-00	*Megaptera novaeangliae*	2	11 04' 60 56'	26.8	38	off
02-Mar-00	*Megaptera novaeangliae*	1	10 30' 60 38'	27.0	40	off
03-Mar-00	*Megaptera novaeangliae*	2	10 34' 60 34'	26.7	48	off
03-Mar-00	*Megaptera novaeangliae*	2	10 29' 60 36'	27.1	40	off
03-Mar-00	*Megaptera novaeangliae*	2	11 04' 60 56'	26.8	38	off
03-Mar-00	*Megaptera novaeangliae*	1	10 30' 60 38'	26.8	40	off
03-Mar-00	*Megaptera novaeangliae*	2	10 34' 60 34'	26.8	48	off
03-Mar-00	*Megaptera novaeangliae*	2	10 29' 60 36'	27.1	40	off
05-Mar-00	*Megaptera novaeangliae*	3	10 36' 60 25'	27.0	71	off
05-Mar-00	*Megaptera novaeangliae*	1	10 49' 60 27'	27.3	84	off
06-Mar-00	*Megaptera novaeangliae*	1	10 52' 60 26'	27.1	71	off
17-Mar-00	*Megaptera novaeangliae**	2	11 10' 63 48'	23.9	31	on
20-Mar-00	*Megaptera novaeangliae*	1	10 49' 60 43'	27.3	44	on
22-Mar-00	*Megaptera novaeangliae*	1	13 16' 59 41'	27.6	295	on
23-Mar-00	*Megaptera novaeangliae*	1	13 17' 59 27'	28.1	522	on
24-Mar-00	*Megaptera novaeangliae*	1	14 58' 60 57'	27.7	71	on
25-Mar-00	*Megaptera novaeangliae*	1	16 24' 60 47'	26.2	390	on
25-Mar-00	*Megaptera novaeangliae*	1	16 09' 61 09'	26.3	27	off
25-Mar-00	*Megaptera novaeangliae*	1	16 09' 61 09'	26.4	27	off
25-Mar-00	*Megaptera novaeangliae*	1	16 06' 61 12'	26.6	309	on
25-Mar-00	*Megaptera novaeangliae*	1	16 06' 61 12'	26.6	309	off
25-Mar-00	*Megaptera novaeangliae*	1	16 05' 61 16'	26.6	311	on
25-Mar-00	*Megaptera novaeangliae*	2	15 59' 61 28'	27.2	309	off
25-Mar-00	*Megaptera novaeangliae*	1	15 57' 61 29'	27.3	306	off
28-Mar-00	*Megaptera novaeangliae*	1	18 50' 66 41'	26.1	3660	on
28-Mar-00	*Megaptera novaeangliae*	1	19 04' 67 13'	26.1	5033	on
29-Mar-00	*Megaptera novaeangliae*	1	20 14' 70 15'	25.5	4160	on

Note: Off-effort sightings from 1 March 2000 to 6 March 2000 are not included in Figure 5.

Table 4. Acoustic detections and estimated numbers of humpback whales

AREA	DATE	ACOUSTIC DETECTIONS (SINGERS = MALES)	ADULT MALES (Nm) = Nsingers/0.55	ADULT FEMALES (Nf) = Nm * (35/65)
St. Kitts & Nevis	17-18 Feb	7	13	7
Antigua - Barbuda	-	no survey		
Montserrat	-	no survey		
Guadeloupe	19-Feb	7	13	7
Dominica	-	no survey		
Martinique	20-21 Feb	7	13	7
St. Lucia	22-Feb	2	4	2
St. Vincent	-	no survey		
Grenada	23-Feb	0	0	1*
Barbados	24-Feb	0	0	0
Tobago & E. Trinidad	27-28 Feb	7	13	7
LEG 1 SUBTOTALS:		30	55	29
Grenada	19-Mar	5	9	5
Tobago & E. Trinidad	20-21 Mar	7	13	7
St. Vincent	-	no survey		
St. Lucia	-	no survey		
Barbados	22-23 Mar	5	9	5
Martinique	24-Mar	7	13	7
Dominica	-	no survey		
Guadeloupe	25-Mar	9	16	9
Monserrat	-	no survey		
Antigua - Barbuda	-	no survey		
St. Kitts & Nevis	-	no survey		
LEG 2 SUBTOTALS:		33	60	32
Venezuela	11-18 Mar	11	20	11

* Note: a cow-calf pair was sighted during the survey effort.

Figure 1. Historical encounters (harvests and sightings) of humpback whales in the eastern and southern Caribbean.

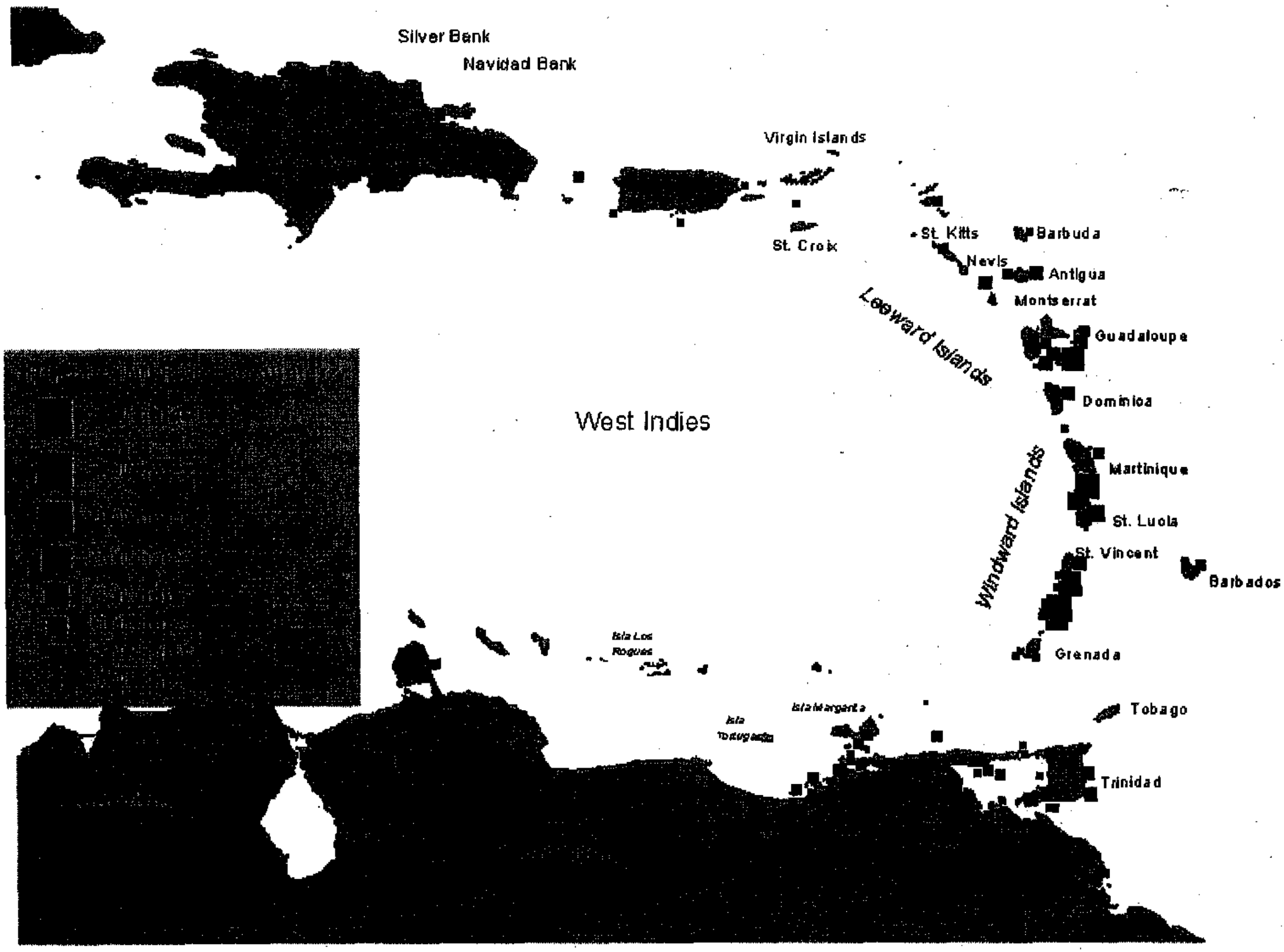


Figure 2. Survey trackline indicating both Leg 1 and Leg 2 tracks.

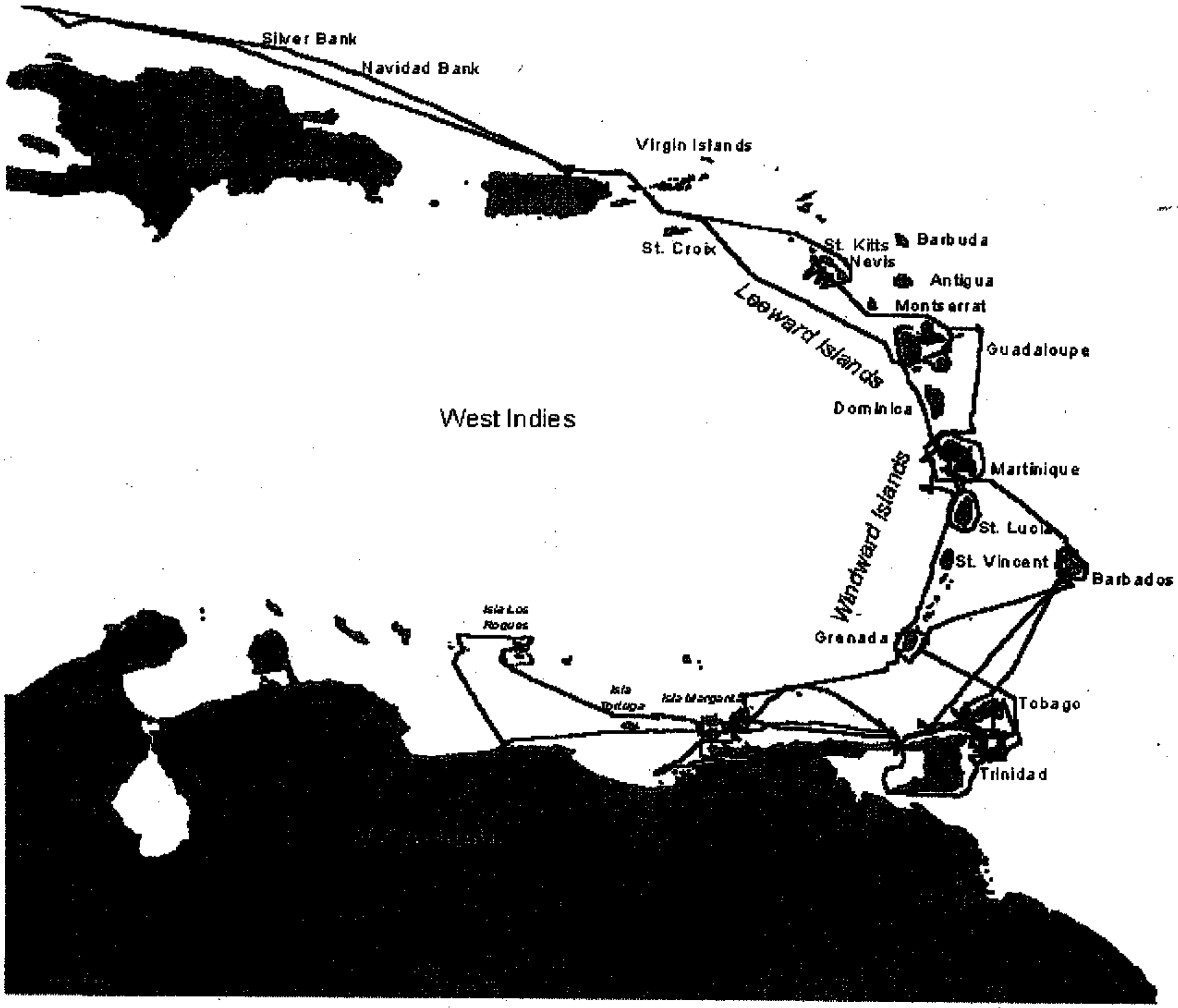


Figure 3. Histogram of sonobuoy-VHF radio reception ranges for 18 sonobuoy deployments.

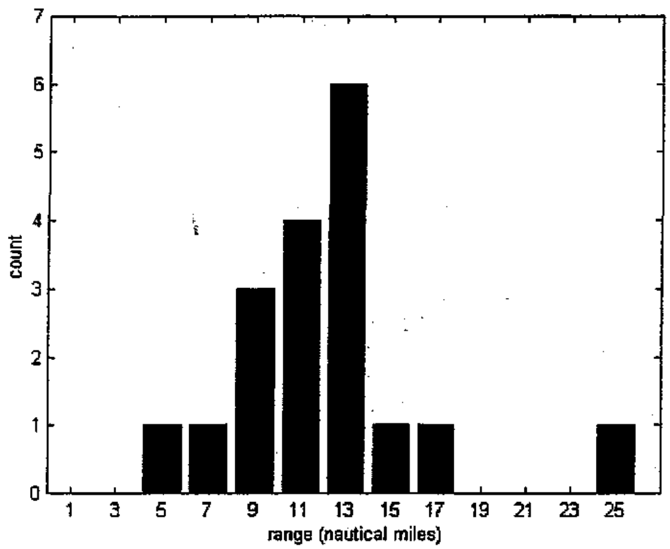


Figure 4. A single singing humpback whale at a bearing of 101^0 magnetic from the sonobuoy. The harmonics of the call are also evident in this bearing plot, confirming the direction of the whale.

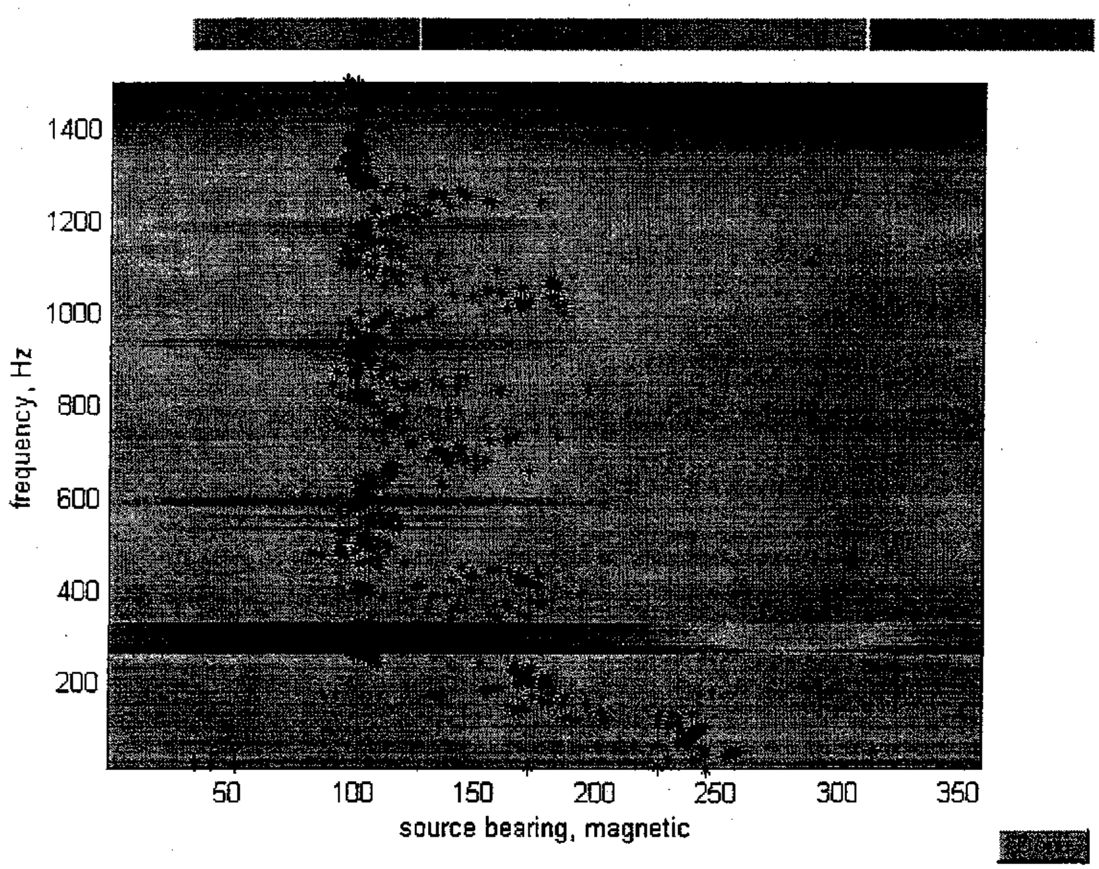


Figure 5. Visual survey effort (lines) and humpback whale sightings (circles).

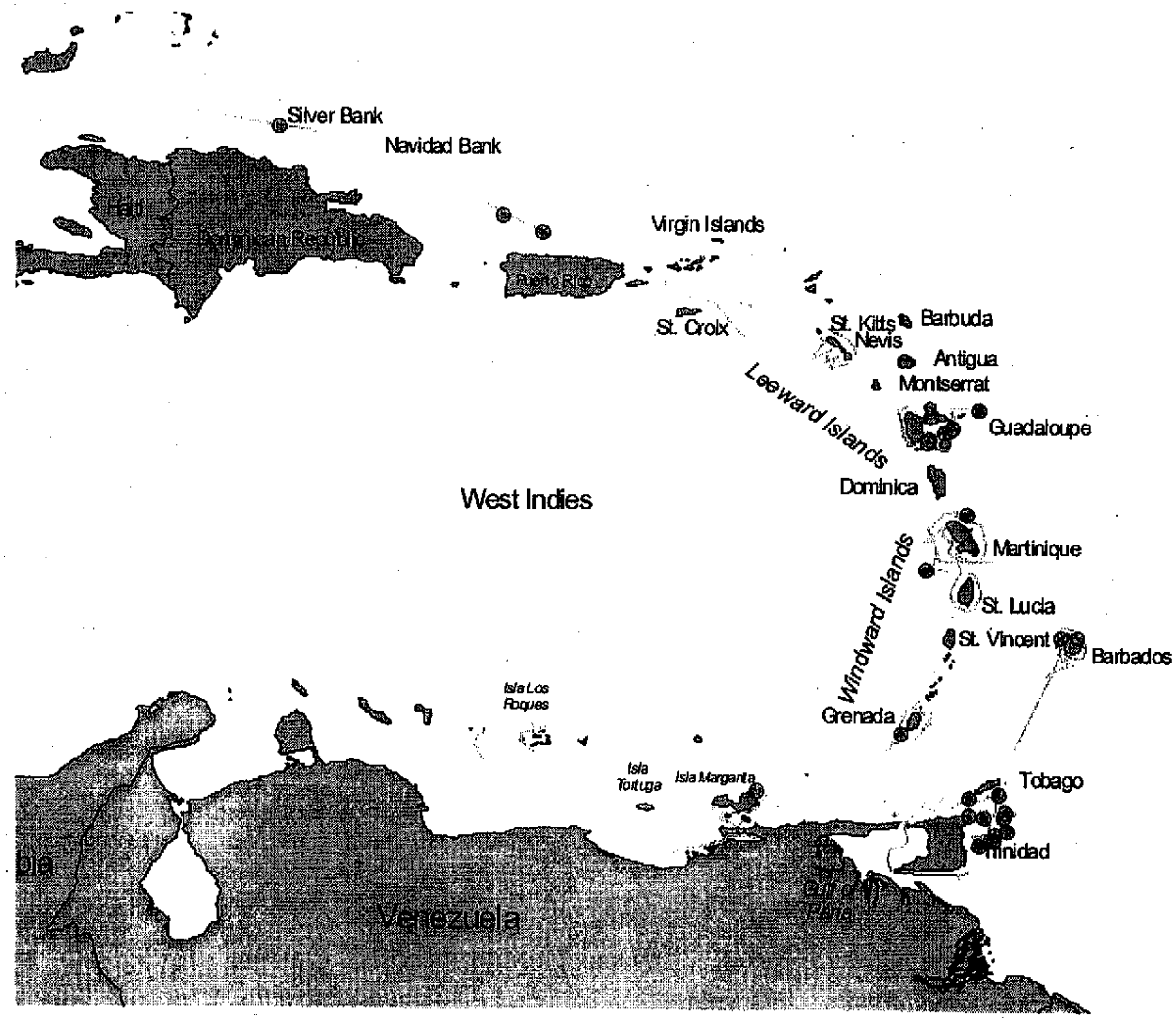


Figure 6. Locations of sonobuoy deployments (circles) along the survey trackline (broken line).

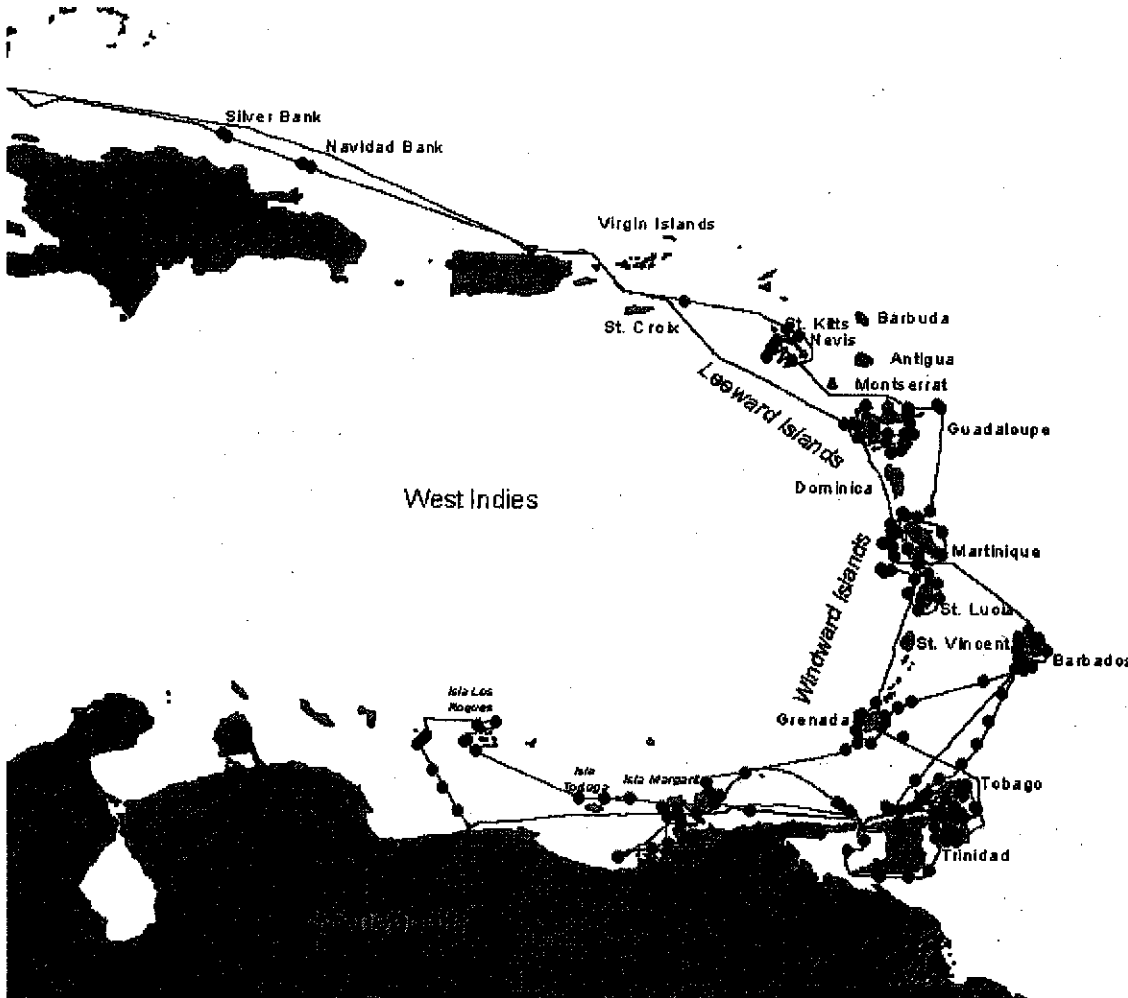
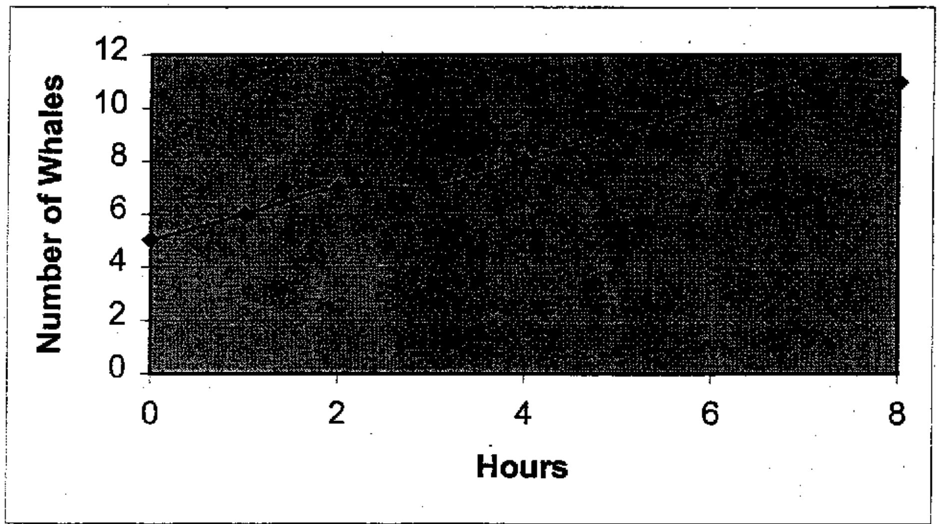


Figure 7. The cumulative number of singing humpback whales acoustically detected on sonobuoys in 5 different locations monitored for at least 8 continuous hours.



Appendix 1. Toponmy (Based on "National Geographic Atlas of the World, Revised Sixth Edition", National Geographic, Washington, D.C. (1996), and "Webster's Ninth New Collegiate Dictionary", Geographical Names, Merriam-Webster, Inc., Springfield, Massachusetts (1995).

West Indies: The islands lying between southeast North America and north South America bordering on the Caribbean and comprising the Greater Antilles, Lesser Antilles, and the Bahamas.

Greater Antilles: Chain of islands in the West Indies including Cuba, Hispaniola, Jamaica, and Puerto Rico.

Lesser Antilles: Chain of Islands in the West Indies including Virgin, Leeward, and Windward Islands, Trinidad, Tobago, Barbados and the islands in the Southern Caribbean north of Venezuela.

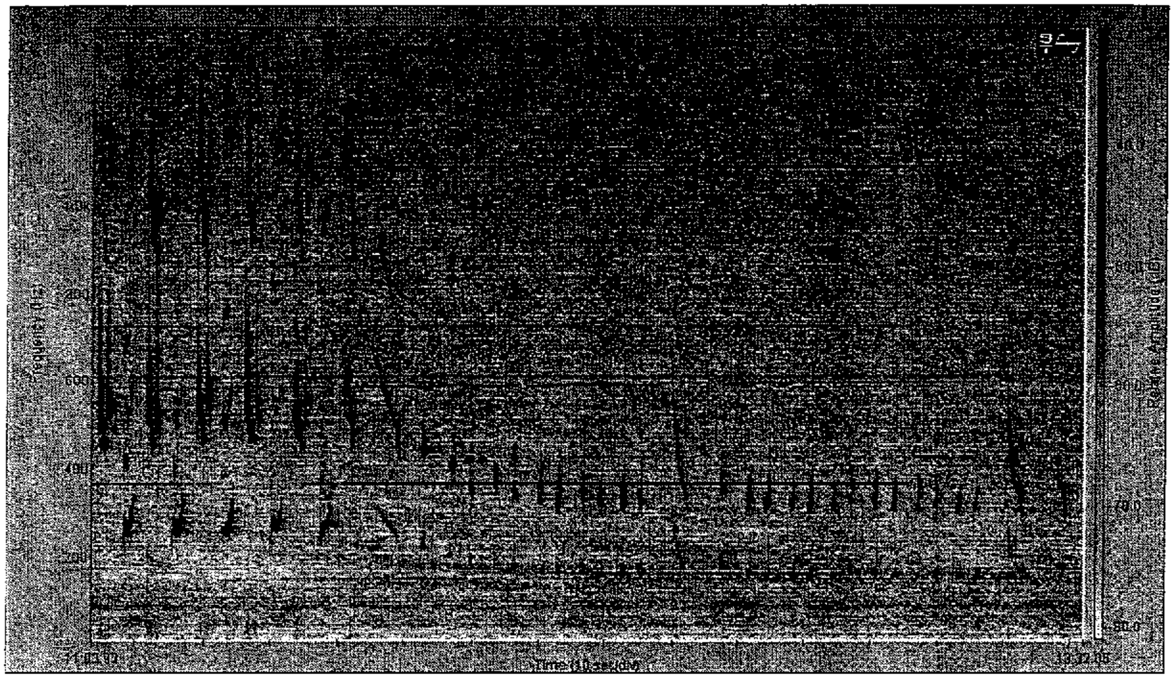
Leeward Islands: the island chain from the Virgin Islands in the north to Dominica in the south.

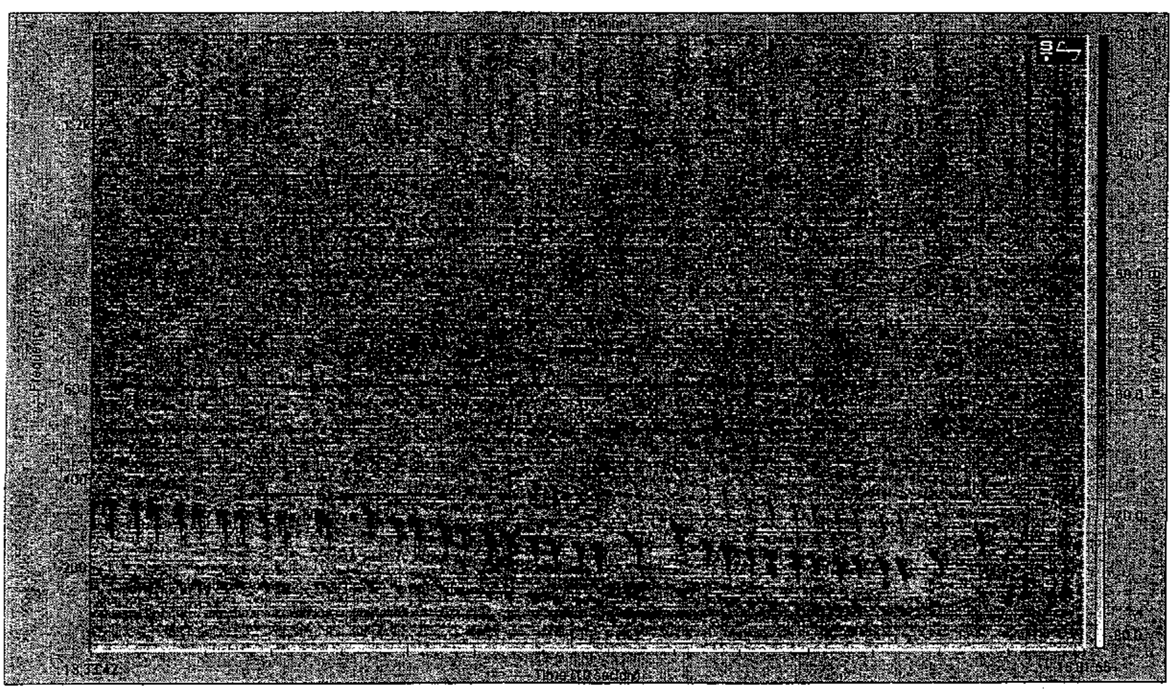
Windward Islands: the chain of islands from Martinique in the north to Grenada in the south, but not including Barbados, Trinidad, or Tobago.

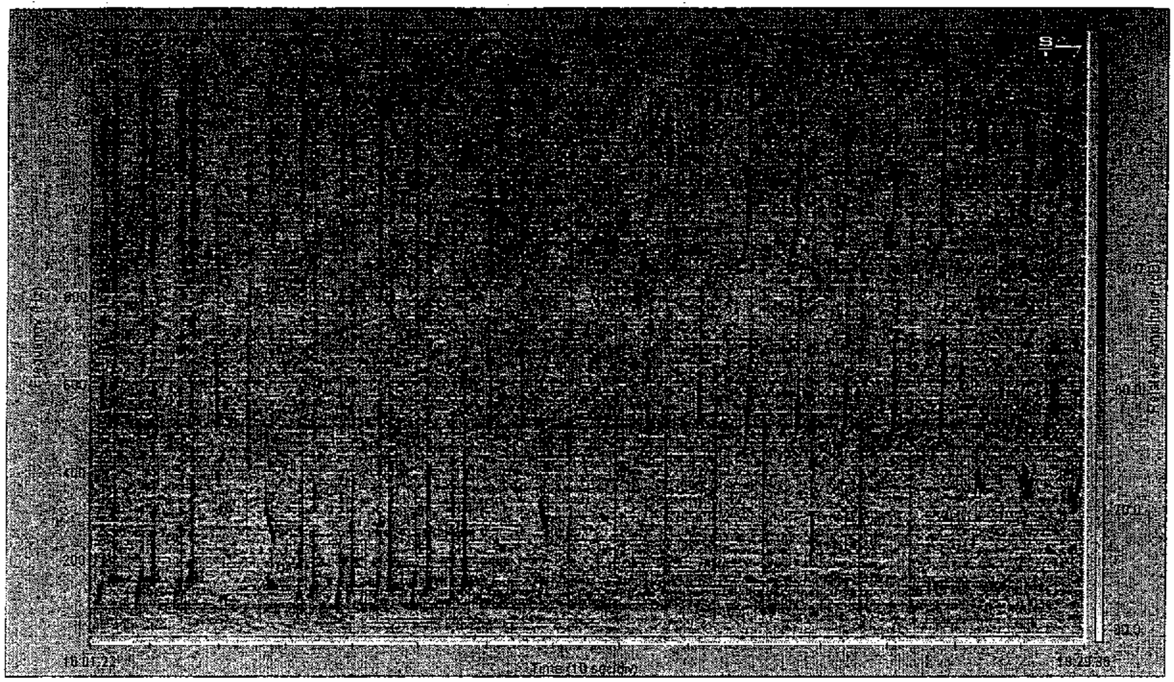
Spanish Main: formerly the northeast coast of South America, between the Orinoco River and the isthmus of Panama, and the adjoining part of the Caribbean Sea.

Primary Survey Area: The Lesser Antilles except for the Virgin Islands, Anguilla and the islands on Anguilla Bank, Sint. Eustatius, Saba and Saba Bank in the Leewards.

Appendix II. Spectrogram of frequently encountered humpback whale song during leg 2 of the survey. This particular song was recorded off the west coast of Barbados.

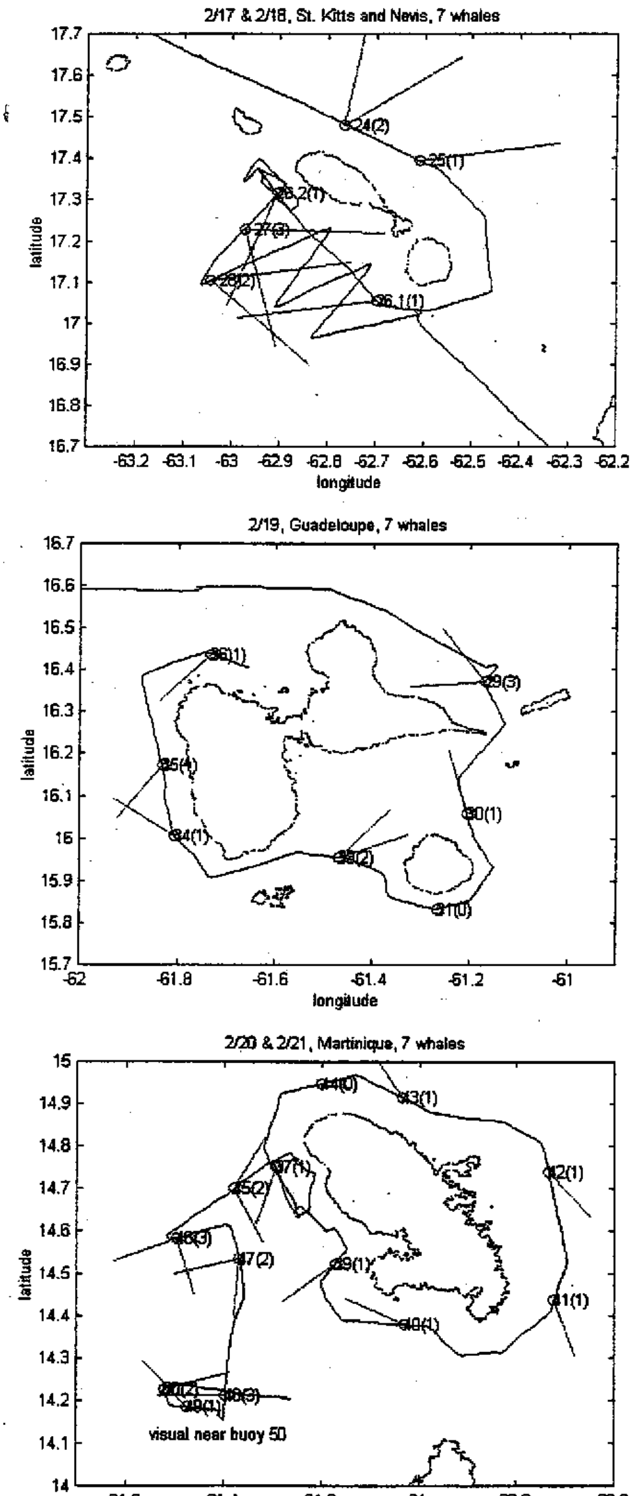


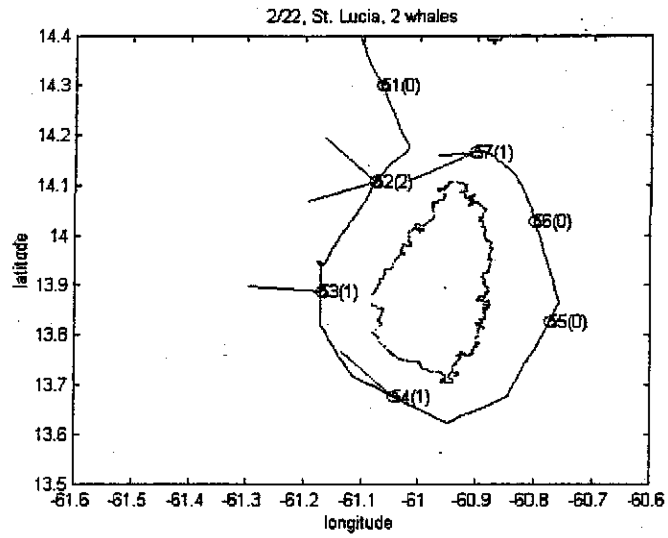


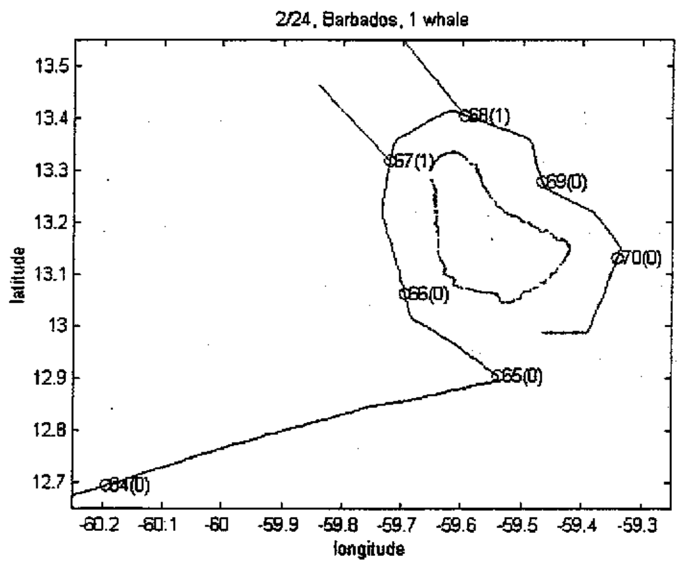


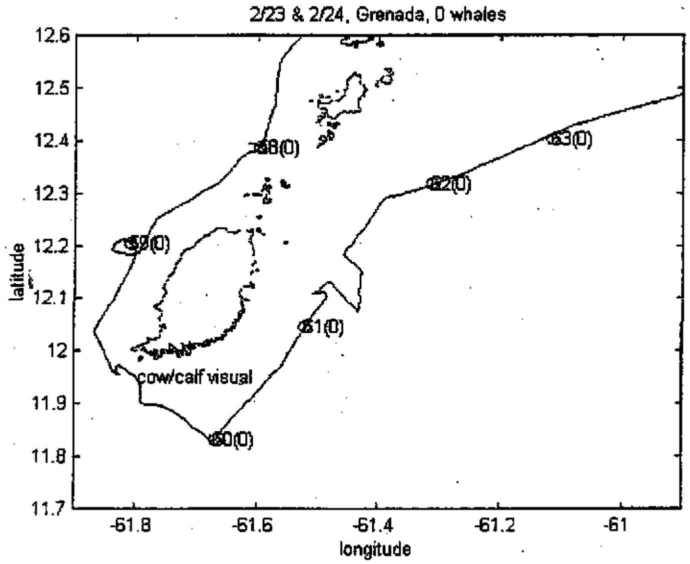
Appendix III.

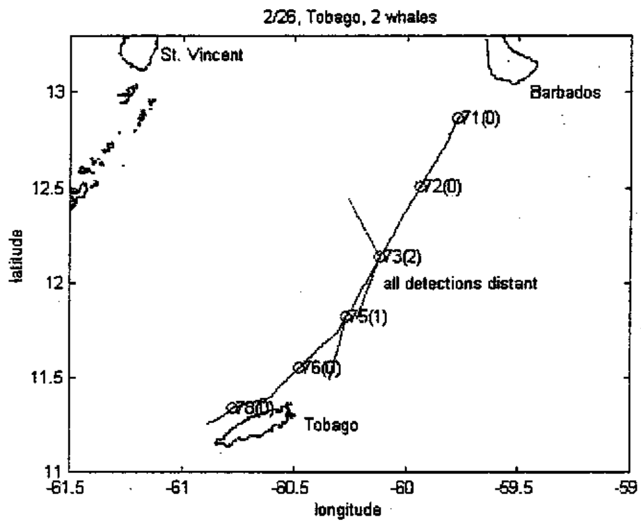
Figure 1.1-1.10. Sonobuoy locations and ship track around each island or survey region- leg 1.

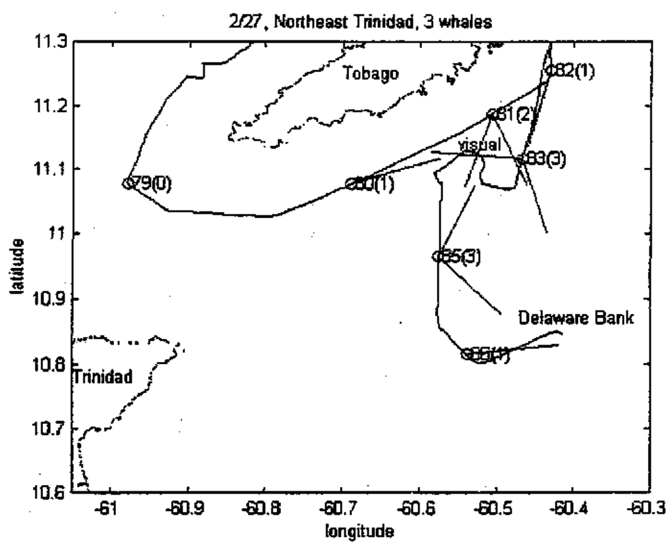


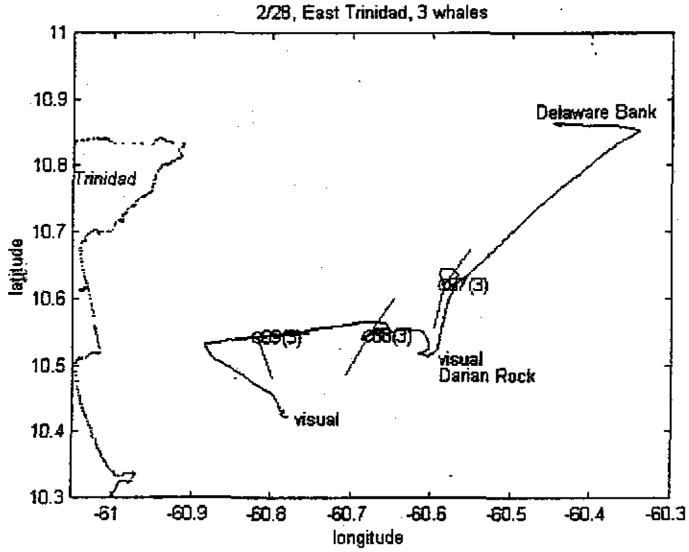

2/22, St. Lucia, 2 whales
latitude
longitude
51(0)
57(1)
52(2)
56(0)
53(1)
55(0)
54(1)


2/24, Barbados, 1 whale
latitude
longitude
68(1)
67(1)
69(0)
70(0)
66(0)
65(0)
64(0)


2/23 & 2/24, Grenada, 0 whales
58(0)
63(0)
62(0)
59(0)
61(0)
cow/calf visual
60(0)
latitude
longitude


2/26, Tobago, 2 whales
St. Vincent
Barbados
71(0)
72(0)
73(2)
all detections distant
75(1)
76(0)
78(0)
Tobago
latitude
longitude


2/27, Northeast Trinidad, 3 whales
Tobago
82(1)
81(2)
visual
83(3)
79(0)
80(1)
85(3)
Delaware Bank
Trinidad
latitude
longitude


2/28, East Trinidad, 3 whales
Delaware Bank
Trinidad
visual
Darian Rock
visual
latitude
longitude
11
10.9
10.8
10.7
10.6
10.5
10.4
10.3
-61
-60.9
-60.8
-60.7
-60.6
-60.5
-60.4
-60.3

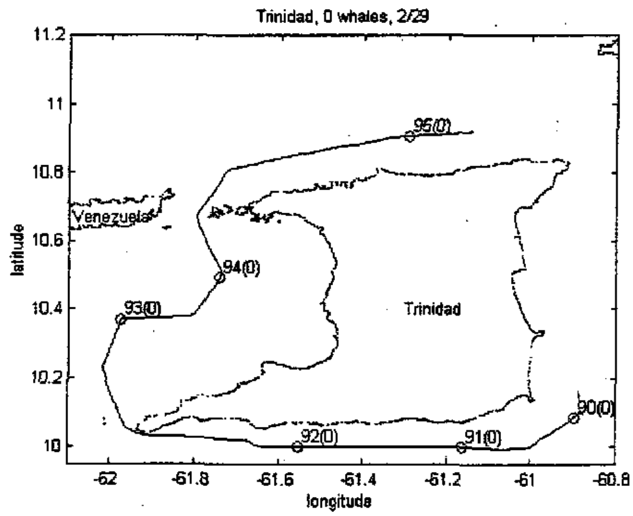
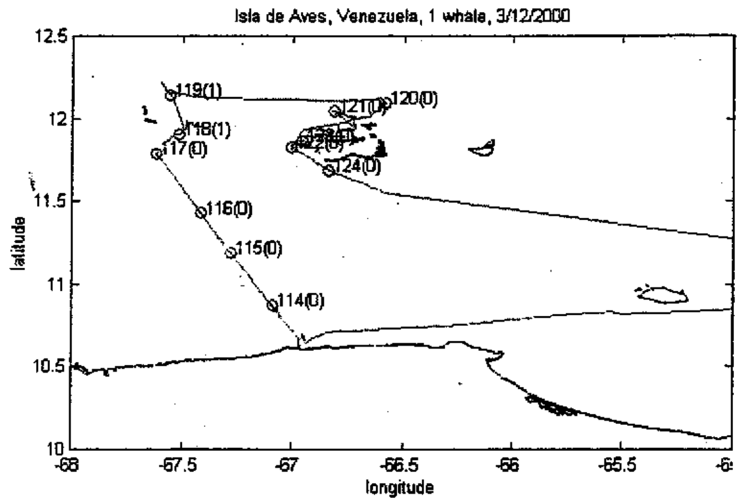
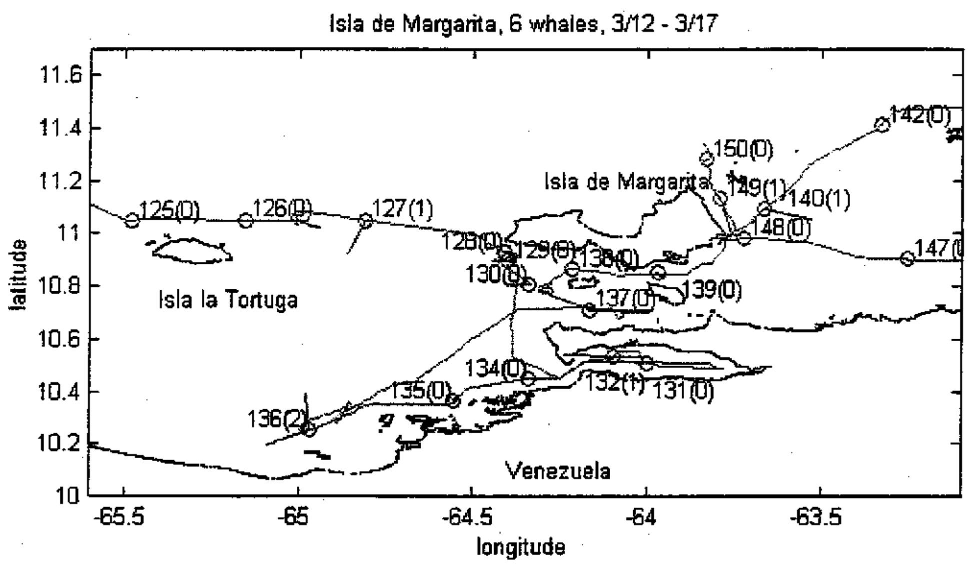
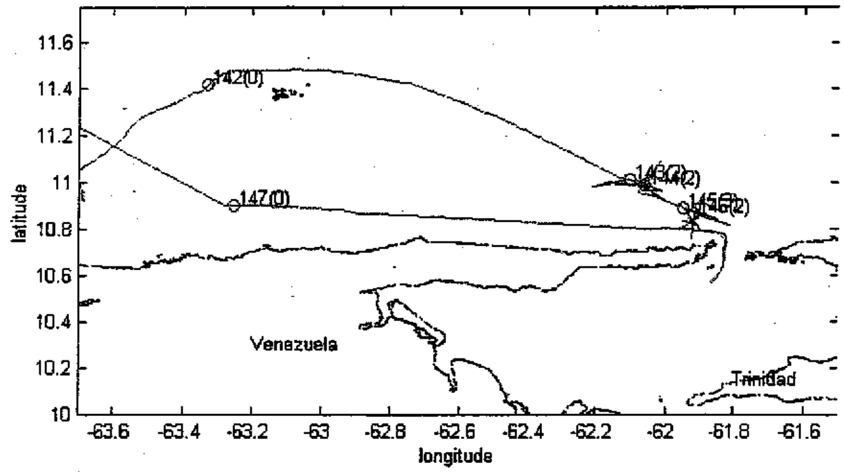

Trinidad, 0 whales, 2/29
Venezuela
Trinidad
95(0)
94(0)
93(0)
92(0)
91(0)
90(0)
latitude
longitude
11.2
11
10.8
10.6
10.4
10.2
10
-62
-61.8
-61.6
-61.4
-61.2
-61
-60.8

Figure 2.1-2.8. Sonobuoy locations and ship track line for each surveyed area- leg 2.

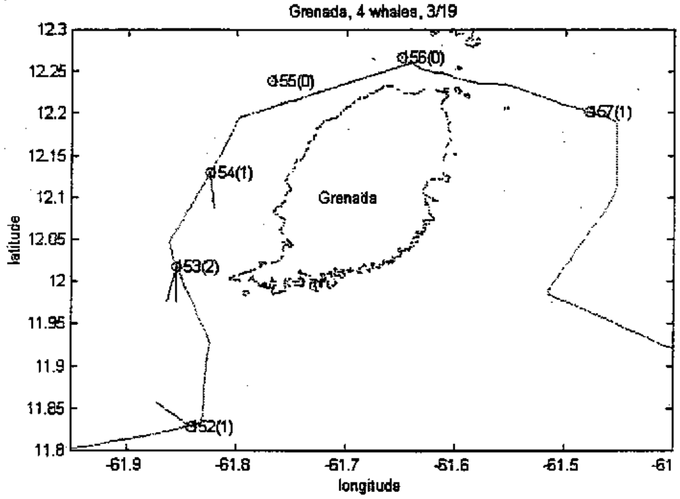




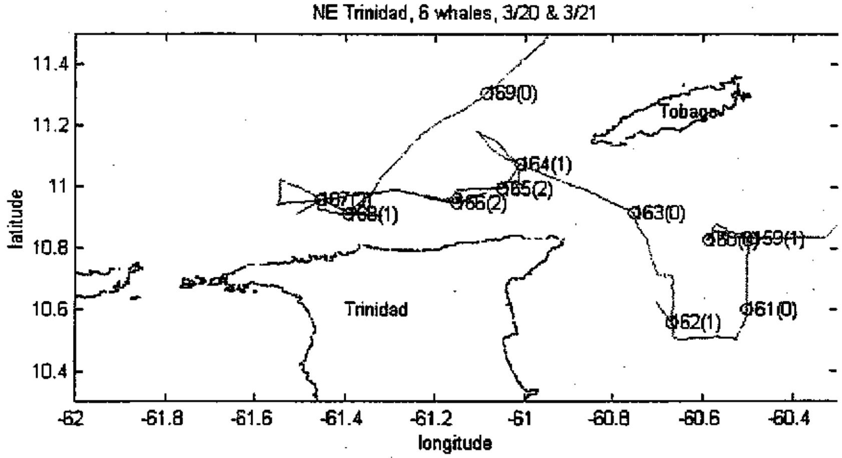
Dragons Mouth, Venezuela, 4 whales, 3/16/2000



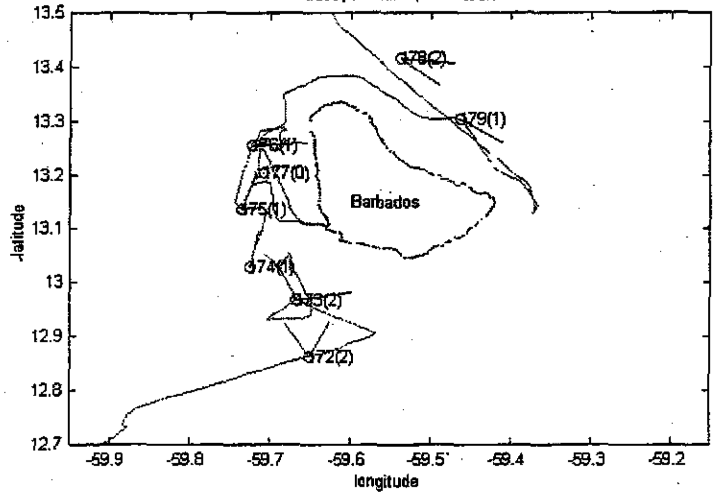
Grenada, 4 whales, 3/19



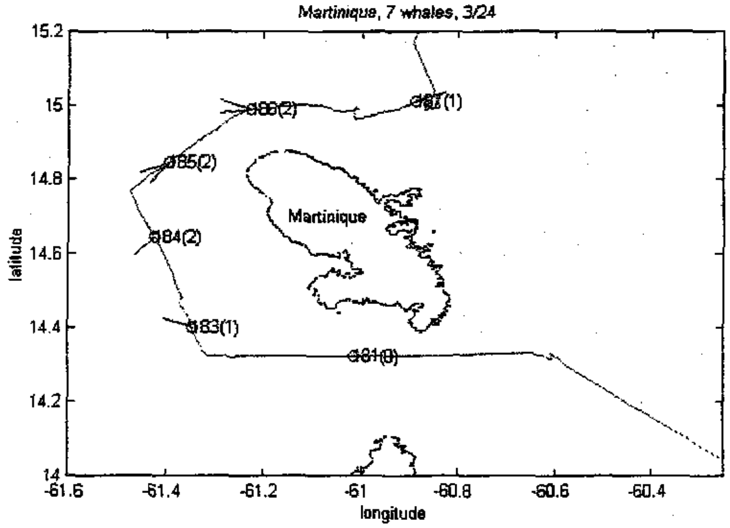
NE Trinidad, 6 whales, 3/20 & 3/21



Barbados, 5 whales, 3/22 & 3/23



Martinique, 7 whales, 3/24



Guadeloupe, 10 whales, 3/25